PATENT COOPERATION TREATY

REC'D 17 JAN 2002
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PCT

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Article 36 and Rule 70)

Applicant's or agent's file reference 57.0359WOPCT	FOR FURTHER ACTION	See Notification of Transmittal of International Preliminary Examination Report (Form PCT/IPEA/416)
International application No. PCT/GB00/03704	International filing date *(day/month/year)* 27/09/2000	Priority date *(day/month/year)* 01/10/1999
International Patent Classification (IPC) or national classification and IPC G01V11/00		
Applicant SCHLUMBERGER HOLDINGS LIMITED		

1. This international preliminary examination report has been prepared by this International Preliminary Examining Authority and is transmitted to the applicant according to Article 36.

2. This REPORT consists of a total of 7 sheets, including this cover sheet.

   ☐ This report is also accompanied by ANNEXES, i.e. sheets of the description, claims and/or drawings which have been amended and are the basis for this report and/or sheets containing rectifications made before this Authority (see Rule 70.16 and Section 607 of the Administrative Instructions under the PCT).

   These annexes consist of a total of sheets.

3. This report contains indications relating to the following items:

   - I ☒ Basis of the report
   - II ☒ Priority
   - III ☒ Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
   - IV ☐ Lack of unity of invention
   - V ☒ Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations suporting such statement
   - VI ☐ Certain documents cited
   - VII ☒ Certain defects in the international application
   - VIII ☐ Certain observations on the international application

Date of submission of the demand	Date of completion of this report
29/03/2001	15.01.2002
Name and mailing address of the international preliminary examining authority: European Patent Office D-80298 Munich Tel. +49 89 2399 - 0 Tx: 523656 epmu d Fax: +49 89 2399 - 4465	Authorized officer Kys, W Telephone No. +49 89 2399 6513

Form PCT/IPEA/409 (cover sheet) (January 1994)

I. Basis of the report

1. With regard to the **elements** of the international application *(Replacement sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to this report since they do not contain amendments (Rules 70.16 and 70.17))*:

   Description, pages:

   1-23 as originally filed

   Claims, No.:

   1-21 as originally filed

   Drawings, sheets:

   1/10-10/10 as originally filed

2. With regard to the **language**, all the elements marked above were available or furnished to this Authority in the language in which the international application was filed, unless otherwise indicated under this item.

   These elements were available or furnished to this Authority in the following language: , which is:

   - ☐ the language of a translation furnished for the purposes of the international search (under Rule 23.1(b)).
   - ☐ the language of publication of the international application (under Rule 48.3(b)).
   - ☐ the language of a translation furnished for the purposes of international preliminary examination (under Rule 55.2 and/or 55.3).

3. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international preliminary examination was carried out on the basis of the sequence listing:

   - ☐ contained in the international application in written form.
   - ☐ filed together with the international application in computer readable form.
   - ☐ furnished subsequently to this Authority in written form.
   - ☐ furnished subsequently to this Authority in computer readable form.
   - ☐ The statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.
   - ☐ The statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished.

4. The amendments have resulted in the cancellation of:

   - ☐ the description, pages:
   - ☐ the claims, Nos.:

☐ the drawings, sheets:

5. ☐ This report has been established as if (some of) the amendments had not been made, since they have been considered to go beyond the disclosure as filed (Rule 70.2(c)):

(Any replacement sheet containing such amendments must be referred to under item 1 and annexed to this report.)

6. Additional observations, if necessary:

II. Priority

1. ☐ This report has been established as if no priority had been claimed due to the failure to furnish within the prescribed time limit the requested:

   ☐ copy of the earlier application whose priority has been claimed.

   ☐ translation of the earlier application whose priority has been claimed.

2. ☐ This report has been established as if no priority had been claimed due to the fact that the priority claim has been found invalid.

Thus for the purposes of this report, the international filing date indicated above is considered to be the relevant date.

3. Additional observations, if necessary:
see separate sheet

III. Non-establishment of opinion with regard to novelty, inventive step and industrial applicability

1. The questions whether the claimed invention appears to be novel, to involve an inventive step (to be non-obvious), or to be industrially applicable have not been examined in respect of:

   ☐ the entire international application.

   ☒ claims Nos. 8,16.

because:

☐ the said international application, or the said claims Nos. relate to the following subject matter which does not require an international preliminary examination (*specify*):

☒ the description, claims or drawings (*indicate particular elements below*) or said claims Nos. are so unclear that no meaningful opinion could be formed (*specify*):
see separate sheet

☐ the claims, or said claims Nos. are so inadequately supported by the description that no meaningful opinion

could be formed.

☐ no international search report has been established for the said claims Nos. .

2. A meaningful international preliminary examination cannot be carried out due to the failure of the nucleotide and/or amino acid sequence listing to comply with the standard provided for in Annex C of the Administrative Instructions:

☐ the written form has not been furnished or does not comply with the standard.

☐ the computer readable form has not been furnished or does not comply with the standard.

V. Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Statement

Novelty (N)	Yes:	Claims	1-17
	No:	Claims	18-21
Inventive step (IS)	Yes:	Claims	6,7,15
	No:	Claims	1-5,12-14, 18-21
Industrial applicability (IA)	Yes:	Claims	1-21
	No:	Claims	

2. Citations and explanations
see separate sheet

VII. Certain defects in the international application

The following defects in the form or contents of the international application have been noted:
see separate sheet

Re Item II : Priority

Priority date of 1.10.99 as claimed could not be verified. Yet, assuming validness the particular relevance of US,A,5 995 446 (publ.: 30.11.99) indicated in the International Search Report with respect to inventive step or even novelty has been disregarded.

Re Item III : Non-establishment of opinion with regard to novelty, inventive step and industrial applicability

In method claims 8, 16 the intended scope of the step "effecting the minimum practical changes" cannot be examined, "minimum practical" being totally open to interpretation.

Re Item V : Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

A. CITATIONS

The documents of the International search report have been introduced:

D1= US,A,5 995 446 (publ.: 30.11.99);
D2= WO,A,97 27502;
D3= US,A,5 838 634;
D4= US,A,4 340 934.

B. EXPLANATIONS

1 Each of the cited documents relates to updating an earth model using borehole measurements, see abstracts.

Novelty in the sense of Article 33(1), (2) PCT

2 The method of claim 1 differs from any of the known methods from D2, D3, D4 by its use for enigmatically "predicting potential problems" and possibly the steps of selecting a component of the earth model that has a high degree of uncertainty and updating the model therewith prior to completing borehole construction. Therefore, the method of claim 1 is considered novel.

3 Comprising the other methods defined in claims 2 to 17 they, too, are considered novel, even though claim 12 is worded formally as an independent claim.

4 Defining a computer readable medium that is capable of causing a computer to perform the steps of claim 1, apparatus claim 18 is not limited to some use in accordance with the method of claim 1 but claims any CD which may store a software program comprising the steps of claim 1. Similarly, according to the other apparatus claims 19-21 further program steps may be stored without effect on the storage medium per se. Examples of such a memory, however, are known from D2, claims 12, 29, 30; D3, col.11, line 63 to col.12, line 14. Hence, the subject-matter of the apparatus claims 18-21 appears to be anticipated by the prior art.

Inventive step in the sense of Article 33(1), (3) PCT

5 Scanning the specification with respect to the first difference above namely an earth model used for predicting potential problems in drilling of a borehole having a predetermined trajectory, it is noted that

- following pp.9/10, the earth model generated prior to drilling typically comprises data concerning drilling hazards, that
- following p.12, a possibly masked signal that the borehole is failing may be provided by cavings analysis, and that
- following p.14, predicted states of wellbore and geological features around it are compared and updated using real-time data.

Thus, it would appear that the step of obtaining such an earth model merely describes daily routine work on the subject of borehole drilling by an odd wording.

6 With respect to the other difference above namely selecting that component of an earth model that has a high uncertainty in view of both evalutions based on the model and data gathered during borehole construction, it would appear that such an approach is standard for upgrading a model, see, eg, D3, col.19, lines 54-56. Furthermore, it is considered obvious to a field engineer to make use of the most up-to-date model available, specially when using real-time measurements.

7 Wording the steps of claim 1 differently such as by giving additional prominence to predicting failure conditions (claims 2, 3, 12) or requesting an iterative updating process (claims 4, 5, 13, 14) is not considered to redress the above objections.

8 It does not appear to follow from the prior art to rank the selected components according to a degree of uncertainty as defined in claims 6, 15 and, at least implicitly, in claim 7, their subject-matter being specified in combination with Fig.5.

Industrial applicability in the sense of Article 33(1), (4) PCT

9 Not questioned, the claims defining application or storage of information about borehole drilling.

Re Item VII : Certain defects in the international application

The description should cite D2, D3 reflecting the above prior art for understanding, refer to Rule 5.1(a)(ii) PCT.

Case No. 57.0359 WO PCT
Scan ....
Local ....
Ack. by Rep. ....x........
... .

WO 01/25823
PCT/GB00/03704

PATENT COOPERATION TREATY

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From the INTERNATIONAL BUREAU

To:
WANG, William, L.
Schlumberger Cambridge Research Limited
Intellectual Property Law Dept.
High Cross
Madingley Road
Cambridge CB3 0EL
ROYAUME-UNI

CH. II ENTRY 1 APR 02
20.4.01
20.4.01
already done

NOTICE INFORMING THE APPLICANT OF THE COMMUNICATION OF THE INTERNATIONAL APPLICATION TO THE DESIGNATED OFFICES

(PCT Rule 47.1(c), first sentence)

Date of mailing (day/month/year) 12 April 2001 (12.04.01)		
Applicant's or agent's file reference 57.0359WOPCT	**IMPORTANT NOTICE**	
International application No. PCT/GB00/03704	**International filing date** (day/month/year) 27 September 2000 (27.09.00)	**Priority date** (day/month/year) 01 October 1999 (01.10.99)
Applicant SCHLUMBERGER HOLDINGS LIMITED et al		

1. Notice is hereby given that the International Bureau has communicated, as provided in Article 20, the international application to the following designated Offices on the date indicated above as the date of mailing of this Notice:
   AU,KP,KR,US

   In accordance with Rule 47.1(c), third sentence, those Offices will accept the present Notice as conclusive evidence that the communication of the international application has duly taken place on the date of mailing indicated above and no copy of the international application is required to be furnished by the applicant to the designated Office(s).

2. The following designated Offices have waived the requirement for such a communication at this time:
   AE,AG,AL,AM,AP,AT,AZ,BA,BB,BG,BR,BY,BZ,CA,CH,CN,CR,CU,CZ,DE,DK,DM,DZ,EA,EE,EP,ES,FI,GB,GD,GE,GH,GM,HR,HU,ID,IL,IN,IS,JP,KE,KG,KZ,LC,LK,LR,LS,LT,LU,LV,MA,MD,MG,MK,MN,MW,MX,MZ,NO,NZ,OA,PL,PT,RO,RU,SD,SE,SG,SI,SK,SL,TJ,TM,TR,TT,TZ,UA,UG,UZ,VN,YU,
   The communication will be made to those Offices only upon their request. Furthermore, those Offices do not require the applicant to furnish a copy of the international application (Rule 49.1(a-bis)).

3. Enclosed with this Notice is a copy of the international application as published by the International Bureau on 12 April 2001 (12.04.01) under No. WO 01/25823

REMINDER REGARDING CHAPTER II (Article 31(2)(a) and Rule 54.2)

If the applicant wishes to postpone entry into the national phase until 30 months (or later in some Offices) from the priority date, a **demand for international preliminary examination** must be filed with the competent International Preliminary Examining Authority before the expiration of 19 months from the priority date.

It is the applicant's sole responsibility to monitor the 19-month time limit.

Note that only an applicant who is a national or resident of a PCT Contracting State which is bound by Chapter II has the right to file a demand for international preliminary examination.

REMINDER REGARDING ENTRY INTO THE NATIONAL PHASE (Article 22 or 39(1))

If the applicant wishes to proceed with the international application in the **national phase**, he must, within 20 months or 30 months, or later in some Offices, perform the acts referred to therein before each designated or elected Office.

For further important information on the time limits and acts to be performed for entering the national phase, see the Annex to Form PCT/IB/301 (Notification of Receipt of Record Copy) and Volume II of the PCT Applicant's Guide.

The International Bureau of WIPO **34, chemin des Colombettes** **1211 Geneva 20, Switzerland** Facsimile No. (41-22) 740.14.35	Authorized officer J. Zahra Telephone No. (41-22) 338.83.38

Form PCT/IB/308 (July 1996)

PATENT COOPERATION TREATY

PCT

INTERNATIONAL SEARCH REPORT

(PCT Article 18 and Rules 43 and 44)

Applicant's or agent's file reference 57.0359WOPCT	**FOR FURTHER ACTION** see Notification of Transmittal of International Search Report (Form PCT/ISA/220) as well as, where applicable, item 5 below.	
International application No. PCT/GB 00/ 03704	International filing date *(day/month/year)* 27/09/2000	(Earliest) Priority Date *(day/month/year)* 01/10/1999
Applicant SCHLUMBERGER HOLDINGS LIMITED		

This International Search Report has been prepared by this International Searching Authority and is transmitted to the applicant according to Article 18. A copy is being transmitted to the International Bureau.

This International Search Report consists of a total of 3 sheets.

[X] It is also accompanied by a copy of each prior art document cited in this report.

1. **Basis of the report**
   a. With regard to the **language,** the international search was carried out on the basis of the international application in the language in which it was filed, unless otherwise indicated under this item.

      [ ] the international search was carried out on the basis of a translation of the international application furnished to this Authority (Rule 23.1(b)).

   b. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international search was carried out on the basis of the sequence listing :

      [ ] contained in the international application in written form.
      [ ] filed together with the international application in computer readable form.
      [ ] furnished subsequently to this Authority in written form.
      [ ] furnished subsequently to this Authority in computer readble form.
      [ ] the statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.
      [ ] the statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished

2. [ ] **Certain claims were found unsearchable** (See Box I).
3. [ ] **Unity of invention is lacking** (see Box II).

4. With regard to the **title,**
   [X] the text is approved as submitted by the applicant.
   [ ] the text has been established by this Authority to read as follows:

5. With regard to the **abstract,**
   [X] the text is approved as submitted by the applicant.
   [ ] the text has been established, according to Rule 38.2(b), by this Authority as it appears in Box III. The applicant may, within one month from the date of mailing of this international search report, submit comments to this Authority.

6. The figure of the **drawings** to be published with the abstract is Figure No. 2
   [X] as suggested by the applicant.
   [ ] because the applicant failed to suggest a figure.
   [ ] because this figure better characterizes the invention.
   [ ] None of the figures.

INTERNATIONAL SEARCH REPORT

International Application No
P[illegible] 00/03704

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G01V11/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G01V

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, COMPENDEX, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
P,X	US 5 995 446 A (MEYER JOERG H ET AL) 30 November 1999 (1999-11-30) column 3, line 23 - line 45 column 4, line 12 - line 50 column 4, line 62 -column 5, line 6; claim 1	1,12,18
A	WO 97 27502 A (BAKER HUGHES INC) 31 July 1997 (1997-07-31) page 1, line 9 - line 16 page 8, line 13 - line 16 page 13, line 10 - line 14 page 38, line 21 -page 39, line 9	1,12,18
A	US 5 838 634 A (HELWICK JR STERLING J ET AL) 17 November 1998 (1998-11-17) column 6, line 48 -column 7, line 67	1,12,18

-/--

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier document but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
13 December 2000	20/12/2000
Name and mailing address of the ISA European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	**Authorized officer** Lorne, B

1

International Application No
P[redacted] 00/03704

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
A	US 4 340 934 A (SEGESMAN FRANCIS F) 20 July 1982 (1982-07-20) claim 1 -----	1,12,18

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
P[illegible]B 00/03704

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
US 5995446	A	30-11-1999	NONE			
WO 9727502	A	31-07-1997	AU	1710897	A	20-08-1997
			GB	2324153	A,B	14-10-1998
			GB	2339908	A,B	09-02-2000
			NO	983432	A	24-09-1998
US 5838634	A	17-11-1998	CA	2251365	A	16-10-1997
			EP	0891562	A	20-01-1999
			NO	984621	A	04-12-1998
			WO	9738330	A	16-10-1997
US 4340934	A	20-07-1982	AU	4614772	A	07-03-1974
			GB	1405311	A	10-09-1975
			NL	7212097	A	09-03-1973

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
12 April 2001 (12.04.2001)

PCT

(10) International Publication Number
WO 01/25823 A1

(51) International Patent Classification[7]: G01V 11/00

(21) International Application Number: PCT/GB00/03704

(22) International Filing Date: 27 September 2000 (27.09.2000)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
9923290.2 1 October 1999 (01.10.1999) GB

(71) Applicant (*for all designated States except CA, FR, MX, US*): SCHLUMBERGER HOLDINGS LIMITED [—/—]; Craigmuir Chambers, Road Town, P.O. Box 71, Tortola (VG).

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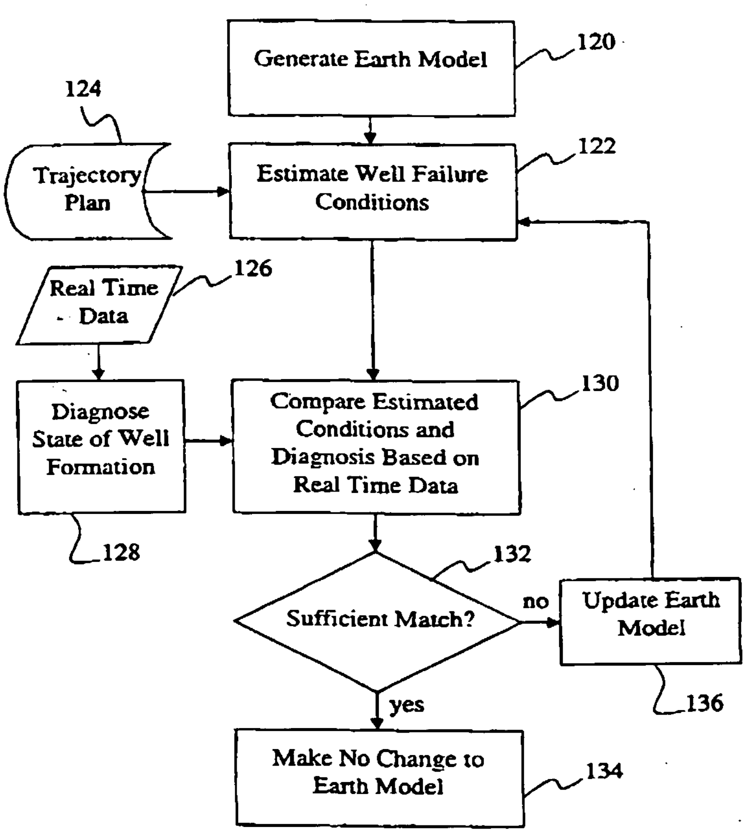
(72) Inventors; and
(75) Inventors/Applicants (*for US only*): BRADFORD, Ian [GB/GB]; 66 Caribou Way, Cherry Hinton, Cambridge, Cambridgeshire CB1 9XG (GB). COOK, John, Mervyn [GB/GB]; 4 Girton Road, Cambridge CB3 0LJ (GB). FULLER, John [GB/GB]; School House, Bentley, Farnham, Surrey GU10 5JP (GB). ALDRED, Walter, David

[Continued on next page]

(54) Title: METHOD FOR UPDATING AN EARTH MODEL USING MEASUREMENTS GATHERED DURING BOREHOLE CONSTRUCTION



(57) Abstract: A method and system for real time updating of an earth model are disclosed. The efficiency with which an oil or gas well is constructed can be enhanced by updating the relevant earth model using real-time measurements of the effective density of the drilling fluid and other parameters. The disclosed method includes generating an earth model used for predicting potential problems in drilling of a borehole having a predetermined trajectory. Evaluations of the state of the borehole and local geological features are obtained which are based on the earth model. Real time data is used to create a diagnosis of the state of the borehole and local geological features. The evaluations are compared with a diagnosis to identify inconsistencies. A component of the earth model is identified that is both related to the identified inconsistency and has a high degree of uncertainty. The selected component of the earth model is then updated prior to completing construction of the borehole using the received data.

WO 01/25823 A1

[GB/US]; 11515 Rock Bend Drive, Houston, TX 77077 (US). **GHOLKAR, Vidhyadhar** [GB/GB]; 77 Appletrees, Bar Hill, Cambridgeshire CB3 8SW (GB).

(74) **Agent: WANG, William, L.**; Schlumberger Cambridge Research Limited, Intellectual Property Law Dept., High Cross, Madingley Road, Cambridge CB3 0EL (GB).

(81) **Designated States** *(national)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CR, CU, CZ, DE, DK, DM, DZ, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW.

(84) **Designated States** *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published:
-- *With international search report.*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

Method for Updating an Earth Model Using Measurements Gathered During Borehole Construction

FIELD OF THE INVENTION:

The present invention relates to the field of drilling oil and gas wells. In particular, the invention relates to a method for updating an earth model during construction of the well.

BACKGROUND OF THE INVENTION:

Earth models contain data which characterise the properties of, and surfaces bounding, the geological features which form the earth's sub-surface, such as rock formations and faults. They are used to assist operations occurring in the earth's sub-surface, such as the drilling of an oil or gas well, or the development of a mine.

The domain of applicability of an earth model varies greatly and should be considered on a case by case basis. Some earth models are applicable only in the near vicinity of a particular oil or gas well, or mine. Others may be valid for an entire oil or gas field, or perhaps even over a region such as the North Sea or Gulf of Mexico.

The data in an earth model consists of measurements gathered during activities such as the seismic, logging or drilling operations of the oil and gas industry, and of interpretations made from these measurements. The data may be gathered above, on, or below the earth's surface.

As the duration or number of sub-surface operations increases, more data is gathered. This data can be used to amend the relevant earth model, with the aim that it should characterise the geology and properties ever more accurately. Clearly, it will be conducive to the efficiency of these operations if amendments which enhance the accuracy of the earth model are made as quickly as possible, or appropriate.

The oil and gas industry's traditional approach to amending earth models has not had a real-time element, apart from using formation integrity, leak-off or extended leak-off tests, or equivalent circulating density (ECD) data in the case of drilling fluid (commonly referred to as "mud") loss while drilling, to constrain the minimum principal in-situ stress. See e.g., Addis et al., 'A comparison of leak-off test and extended leak-off test data for stress estimation', paper SPE/ISRM 47235 presented at the 1998 Eurock Rock Mechanics in Petroleum Engineering Conference, Trondheim, July 8-10 (hereinafter "Addis et al., 1998"). Measurement-while drilling (MWD) data, logging-while drilling (LWD) data, wireline logs, results from tests performed on core, drilling experience and perhaps other information are used to amend the relevant earth model using techniques identical to those used to generate the original version of the earth model. An example of these conventional techniques are described in a publication by Schlumberger Educational Services entitled 'Log interpretation principles/applications', Houston, Texas

(1987), incorporated herein by reference and hereinafter referred to as "(Schlumberger, 1987)".

This traditional approach has been enhanced in order to improve the handling of very severe wellbore instability problems in the Cusiana field in Colombia. See, Last, N., Plumb, R.A., Harkness, R., Charlez, P., Alsen, J. and McLean, M.: 'An integrated approach to evaluating and managing wellbore instability in the Cusiana field, Colombia, South America', paper SPE 30464 presented at the 1995 Annual SPE Technical Conference, Dallas Oct. 22-25, incorporated herein by reference and hereinafter "Last *et al.* (1995)." Last describes an integrated approach to evaluating and managing wellbore instability. An earth model was constructed using data from existing wells, together with results obtained using a computational analysis tool which modelled the geological structure and the in-situ stress state. This allowed the upper and lower bounds to the drilling fluid density to be estimated, provided that the well trajectory was specified, using standard techniques.

As a well was drilled, a data acquisition programme which included cavings monitoring and measurements-while-drilling allowed the failure mechanisms of the rock formations to be characterised and as well as the identification and implementation of appropriate drilling practices. This led to faster, more efficient, well construction. The earth model was updated after a well or hole section had been completed using all available data, particularly (a) downhole images of borehole geometry, fractures, faults and

bedding, (b) stress measurements such as extended leak-off tests, (c) results from tests made on core, and (d) four-arm calliper logs, where available. Measurement-while-drilling techniques were used to characterise time-dependent hole geometry in particular hole intervals.

The approach of Last *et al.* (1995) enhanced the analysis of formation instability that can be made while drilling, with the minimum horizontal stress also being updated in real-time. The understanding of the nature of the formation instability led to improved drilling practices allowing the wells they studied to be constructed much more efficiently.

However, the approach of Last *et al.* (1995) has many limitations, including the following. First, no constitutive parameter or component of the in-situ stress state, other than the minimum principal stress, was updated in real-time. Such parameters were updated after drilling had been completed, using measurements made by wireline tools, in addition to the data gathered in real-time. Second, LWD measurements, such as resistivity and sonic, were not extensively used. This inhibited the diagnosis of the instability mechanisms. Due to these limitations, it was not possible to quantify amendments to drilling practices, apart from updating the value of ECD above which drilling fluid is lost to the formation.

SUMMARY OF THE INVENTION:

Thus, it is an object of the present invention to provide a method to increase the

efficiency with which an oil or gas well can be constructed.

It is a further object of the present invention to provide a method in which amendments that enhance the accuracy of the earth model are made quickly and efficiently.

It is a further object of the present invention where one or more inconsistencies are identified to provide a method of selecting which component or components of an earth model to update.

According to the present invention the efficiency with which an oil or gas well is constructed can be enhanced by updating the relevant earth model using real-time measurements of the effective density of the drilling fluid and at least one other parameter. Updating the earth model need not occur on a continuous basis, but on a timescale appropriate to this construction process. As used herein the term "real-time" is defined to mean as the well or borehole is being constructed. That is, the data acquisition can occur continuously (e.g. measurement while drilling data), or at discrete times (e.g. palaeontological analysis of rock carried by the drilling fluid from the wellbore) and still be considered "real-time".

A method for updating an earth model is provided that includes obtaining an earth model used for predicting potential problems in drilling of a borehole having a predetermined trajectory. Evaluations of the state of the borehole and local geological features are obtained which are based on the earth model. Data is received that has been gathered

during the construction of the borehole. The evaluations are compared with a diagnosis of the state of the borehole and local geological features to identify at least one inconsistency. A component of the earth model is identified that is both related to the identified inconsistency and has a high degree of uncertainty. The selected component of the earth model is then updated prior to completing construction of the borehole using the received data.

Preferably, the evaluations of the state of the borehole and local geological features are predictions of one or more conditions under which the borehole will fail, and they are obtained by combining the earth model with the predetermined trajectory of the borehole.

Preferably, the process is repeated until a sufficient match exists between the predicted failure conditions and the diagnoses of the borehole.

Preferably, the earth model component that will be updated is selected by first identifying components of the earth model that are relevant to the identified inconsistency and then ranking the identified components according to the degree of uncertainty. The component selected is preferably updated using the minimum changes needed to eliminate an identified inconsistency.

Preferably, the received data includes the effective density of the drilling fluid used in the construction of the borehole and one at least other parameter, and the selected component is updated by

using the effective density and at least one other parameter.

The invention is also embodied in a method for drilling a borehole using an earth model that is updated according to the invention. The invention is also embodied in a computer readable medium that is capable of causing a computer to update the earth model according to the invention.

BRIEF DESCRIPTION OF THE DRAWINGS:

Figure 1 illustrates the construction of a borehole according to a preferred embodiment of the invention;

Figure 2 shows a flow chart of a method of updating an earth model, according to a preferred embodiment of the invention;

Figures 3a and 3b show examples of angular cavings that have become detached from the wellbore wall when breakouts occur;

Figure 4 is a schematic representation of breakouts and drilling induced fractures in a vertical well embedded in an isotropic rock formation;

Figure 5 is a flow chart illustrating in greater detail the preferred method of updating the earth model according to the present invention;

Figure 6 illustrates an example of the minimum principal in-situ stress in an earth model;

Figure 7 illustrates an example of the mud window estimated prior to drilling a well;

Figure 8 illustrates an example of drilling hazards derived from an analysis of experience drilling offset wells and the well trajectory shown in Figure 9;

Figure 9 illustrates the trajectory of the well used in the examples of Figures 6-11;

Figure 10 illustrates the in-situ stress state prior to drilling the well used in Figures 6-11; and

Figure 11 illustrates an example of the formation strength in the example of figure 6-11.

DETAILED DESCRIPTION OF THE INVENTION:

The present invention advantageously increases efficiency with which an oil or gas well is constructed by updating the relevant earth model using real-time measurements. Preferably, the real-time measurements are ECD and at least one other parameter, which can gathered using common commercially available methods. For example, the ECD data may be obtained using such as Schlumberger's Annular Pressure While Drilling APWD measurements. See e.g., Schlumberger Oilfield Review: 'Using Downhole Annular Pressure Measurements to Improve Drilling Performance', Sugar-Land, Texas, Winter 1998 incorporated herein by reference and hereinafter referred to as "Schlumberger (1998)".

Figure 1 illustrates the construction of a borehole according to a preferred embodiment of the

invention. Borehole 102 is being drilled into Earth 100. Rig 104 is located at the surface and is used to support the drilling operation. Drill bit 110 is located at the bottom of the borehole and is connected to the rig via drill string 106. Also shown is a LWD or MWD tool 108 that is capable of making measurements during the drilling operation. The dashed line 114 shows the planned borehole trajectory. Offset well 116 is also shown, along with rig 118. Although in the example of Figure 1 the boreholes are shown being drilled on land, the invention is also applicable to offshore drilling operations. Control station 112 is shown schematically, and contains one or more computers that are used to store the earth model, receive measurements from the downhole tools, and update the earth model according to the preferred embodiments described herein. The control station 112 is shown to be located near the rig 104, however in general the control station can be located remotely. Alternatively, some portions of the control station could be located remotely while other portions are located near to the borehole.

Figure 2 shows a flow chart of a method of updating an earth model, according to a preferred embodiment of the invention. In step 120, prior to drilling a well and applying the invention, an earth model is generated with seismic, logging and offset well data using techniques which are publicly documented (See, e.g., Last *et al.* (1995), Schlumberger, 1987). The data contained in the earth model is defined herein as the "components" of the

earth model. The types of data or components contained in an earth model typically consists of: (1) Surfaces bounding geological features, (2) Constitutive parameters of the rock. These describe the mechanical response of rock under load, (3) Stress state and pore pressure, (4) Nature and severity of the drilling hazards associated with each geological feature and/or trajectory. The drilling hazards are categorised from a list which includes hole cleaning, sloughing, chemical activity, undergauge hole, interbedded sequences, faults, naturally fractured formations, formations with weak planes, mobile formations and permeable formations (this list is not exhaustive and further categories can be envisaged), and (5) Any other parameter that may prove to be useful for real-time analysis, such as gamma-ray measurements which characterise the radioactive nature of a formation.

In step 122, the earth model is combined with the planned well trajectory 124, in order to estimate the upper and lower bounds to the drilling fluid density, together with the drilling hazards and their severity at discrete points along the trajectory. Step 122 may be accomplished using standard techniques, such as those outlined in Fjaer, E., Holt, R.M., Horsrud, P., Raaen. A.M., and Risnes, R.: 'Petroleum Related Rock Mechanics', Elsevier, Amsterdam (1992), incorporated herein by reference and hereinafter referred to as "Fjaer *et al.* (1992)." More sophisticated analyses could also be used which may involve concepts such as elastoplastic modelling. See e.g. Bradford, I.D.R., Fuller, J.A., Thompson, P.J.,

and Walsgrove, T.R.: 'Benefits of assessing the solids production risk in a North Sea reservoir using elastoplastic modelling', paper SPE/ISRM 47360 presented at the 1998 Eurock Rock Mechanics in Petroleum Engineering Conference, Trondheim, July 8-10 Incorporated herein by reference and hereinafter referred to as "Bradford *et al.*, (1998)." Although the earth model is shown to be generated in step 120 and the estimations performed in step 122, the earth model and the estimates could be obtained through other means such as receiving them from an outside service provider.

As the well is being drilled, the nature and severity of instability mechanisms, together with the conditions under which they occur, are identified, or diagnosed, in step 128. The extent of any instability, which is defined as the length of wellbore over which formation failure is occurring, may also determined. The diagnosis of step 128 can be carried out by the method disclosed in Last *et al.* (1995). However, a more extensive use of real-time MWD and LWD measurements is preferably used for the diagnosis.

According to a preferred embodiment, in step 128, diagnosing the nature, severity and extent of wellbore instability mechanisms should include the following considerations.

1. There should be sufficient familiarity, prior to commencing operations, with the upper and lower bounds of the drilling fluid density (these define the "mud window") and the anticipated severity of any instabilities.

2. The mud density and ECD should be monitored continuously, particularly in relation to the mud window calculations in order to assess the likely degree of breakouts and the possibility of mud losses. When the mud is stationary, as is the case during connections, the ECD equals the mud density. During drilling, or while circulating off bottom, the ECD typically exceeds the mud density by up to 0.5-1.0 lb/gal. During trips, when equipment is being pulled up and down the well, the ECD below the bit is typically 0-0.5 lb/gal less and more, respectively, than the mud density.

3. The behaviour of the drillpipe and bottom hole assembly (BHA), hole cleaning, rate of penetration (ROP), trajectory, cavings rate and morphology, mud losses/gains and chemistry, together with resistivity, gamma-ray, compressional slowness and caliper LWD measurements should also be continuously monitored. It is then possible to conduct the following evaluations:

(a) Cavings analysis can provide a signal that the borehole is failing and indicates the troublesome formations. Tabular, angular or splintered cavings indicate that the nature of the instability is natural fracturing or weak planes, breakouts and over-pressure, respectively. The cavings rate indicates the level of failure. However, if the hole cleaning is inadequate, not all of the debris generated by any instability may be discharged from the well, thereby masking the severity of the problem. This issue is discussed fully below.

(b) Mud losses occur in naturally fractured zones, faults or drilling induced fractures. Such an event indicates that the fluid pressure in the annulus has exceeded the minimum in-situ principal stress. Mud gains indicate the pore pressure has exceeded the mud pressure or that previously lost mud is being returned to the wellbore due to fracture closure. Such an event allows the pore pressure estimate to be refined. In areas where there is chemical instability, a more comprehensive mud analysis programme may be required.

(c) Gamma-ray data enables formation boundaries to be identified. Some characterisation of the formation may also be possible, if the data is combined with other measurements such as resistivity.

(d) Resistivity measurements allows fracture identification. Schlumberger's LWD tool measures the resistivity at various depths (See e.g., Schlumberger (1998)); the degree of oil based mud invasion into water filled fractures can therefore be determined.

(e) Compressional slowness characterises pore pressure and formation strength.

(f) Caliper measurements of hole enlargement, if available, will identify the unstable formations.

(g) The ROP and hole cleaning efficiency form the key links between wellbore instability and operations. Rock debris in the annulus, resulting from drilling and/or wall failure, will increase if hole cleaning is inadequate, raising the risk of pack-offs, stuck pipe and tools lost in hole. For and explanation of these terms, see Bourgoyne, A.T., Chenevert, M.E.,

Millheim, K.K. and Young, F.S.: 'Applied Drilling Engineering, SPE Textbook Series, Vol. 2 (1991), incorporated herein by reference. The ability to clean the hole is also related to the ROP. At sufficiently high ROP's, the rate of influx of debris into the annulus, from drilling and newly exposed rock which may be failing, will exceed the rate at which material can be discharged from the well, leading to the consequences outlined above.

A reliable diagnosis of the instability mechanism preferably uses all available data. If tabular cavings, due to natural fracturing, are observed, then the resistivity log should be checked for evidence of mud invasion into fractures and the mud records require examining for losses. Similarly, if splintered cavings due to over-pressured formations are seen then high gas levels, kicks or mud gains may also be present. The observation of angular cavings due to breakouts requires the debris levels in the hole to be discerned. In all cases, the cavings volume should be compared to the ECD and the degrees of tight hole and restricted circulation to discern the effectiveness of the hole cleaning and the severity of instability.

In step 130, the states of the wellbore, and geological features adjacent to it, that are predicted using the earth model are compared with those diagnosed using real-time data. If differences exist between the predicted and diagnosed states then the earth model is updated. The comparison of the estimated conditions and the real time based diagnosis should be considered to "match" when the two conditions are within a

reasonable range. For example, according to a preferred embodiment, if the mud pressure at which moderately severe breakouts occurred is not within 2 percent of the value estimated in step 122, then they considered inconsistent and a "sufficient match" in step 132 does not exist. However, the individual thresholds for each compared condition will have to be determined on a case-by-case basis.

According to a preferred embodiment, real-time data 126 includes measurements of the ECD and at least one other parameter. Preferably, these measurements are used in the comparison of diagnosed states with predictions derived from the earth model in step 130, and in the updating of the earth model, which discussed more fully below.

For example, in a vertical well, suppose the ECD exceeds the estimated lower bound of the drilling fluid density and that a steady stream of cavings is being carried from the hole. If the cavings have an angular morphology, then breakouts have occurred, albeit at a higher than expected drilling fluid pressure, as indicated by the ECD data. As the pressure of the drilling fluid decreases, zones of shear failure develop that are centred about the line of action of the minimum horizontal in-situ stress. The material in these zones eventually drops into the wellbore, leading to the cavings shown in Figures 3a and 3b. Conversely, as the drilling fluid pressure increases, fractures develop centred about the line of action of the maximum horizontal in-situ stress.

According to a preferred embodiment, following are four examples of situations in which there would be an insufficient match in step 132 and the earth model would therefore be updated:

1. Breakouts occur, or the fluid is lost to the formation, at values of ECD that differ from those that are predicted;

2. The nature, severity or extent of the drilling hazards differ from their prognosis;

3. Geological characteristics (e.g. the location of formation tops with respect to the trajectory) differ from their prognoses; or

4. Fluid or gas unexpectedly enters the wellbore indicating that estimates of the pore pressure are inaccurate.

Referring again to Figure 2, in this example a sufficient match would not exist in step 132. Accordingly, the earth model would be updated in step 136. In this example, the in-situ stress state, the formation strength, or both of these quantities should be amended so that the predicted and actual states match adequately.

According to a preferred embodiment, the components of the earth model that are the most uncertain should be given priority in the updating process. This advantageously allows for the most efficient and accurate updating of the earth model. Figure 5 is a flow chart illustrating in greater detail the preferred method of updating the earth model according to the present invention. Steps 150, 152 and 154 correspond to step 136 in Figure 2, whereas steps

122, 130, 132 and 134 correspond to the same steps in both figures 2 and 5.

In step 150 the components that are relevant to the inconsistency are determined. In cases where there are more than one inconsistency is identified in the comparison step 130, the most hazardous inconsistency is generally addressed first. In step 152 the relevant components identified in step 150 are ranked according to certainty. In other words, the earth model components that are most unreliable are identified, and preferably, ranked in order of reliability. Alternatively, step 150 can be skipped and the ranking step 152 applied to all or some predetermined number of most uncertain components. The goal of steps 150 and 152 are to identify the most unreliable or most uncertain components or parameters in the earth model so that the update can be focused on those components.

In step 154 the most uncertain components are updated. According to a preferred embodiment, the components that are updated are ideally altered by the smallest degree needed to allow matching of the predicted and measured components.

As discussed above, in steps 122, 130, 132, and 134 failure conditions are estimated, and comparison is made to determine if there is a sufficient match between the estimated conditions and the real time diagnosis. If there is a sufficient match, no further changes are made to the earth model. When a sufficient match is not found, steps 152, 154 122, 130 and 132 are repeated as shown in Figure 5.

When step 152 is being repeated, the recently amended components are preferably re-ranked as being more certain due do their recent amendment. When step 122 is being repeated, the well failure conditions are re-estimated using the updated components.

Following is an example the process described in Figure 5. If real-time compressional slowness data is available through use of the appropriate LWD tool, then the formation strength estimate can be inferred from this measurement and the formation strength is assumed to be the most reliable component in step 154. In step 154, the minimum change to the in-situ stress state (actually the maximum principal in-situ stress, as the minimum principal in-situ stress is constrained using a combination of fluid loss and ECD data) should then be made which allows the predicted and measured pressures at which breakouts occur to adequately match, with the latter determined using ECD data. If real-time compressional slowness data is not available, then it is assumed that the formation strength is the most unreliable (or least certain) parameter or component in step 152. In step 154, the formation strength is updated until prediction and reality match adequately.

Following are further examples of how the earth model updating processes in steps 150, 152 and 154 could be carried out, according to the invention. In particular, if breakouts or fluid losses do not occur as anticipated then the in-situ stress state and formation strength predictions should be amended. More specific examples are as follows.

Suppose the ECD exceeds the anticipated minimum principal in-situ stress without fluid loss. The minimum principal in-situ stress should be amended to be equal to the maximum ECD encountered over the appropriate interval. The new estimate of the minimum principal in-situ stress will be a lower bound to the true value, but will be more accurate than the existing prediction.

Suppose fluid loss occurs at an ECD lower than the minimum principal in-situ stress. The minimum principal in-situ stress should be set to the ECD at which the fluid loss occurred. This will require a comparison of the time based ECD and drilling fluid volume logs.

Suppose breakouts occur at a value of the ECD higher than the minimum value predicted; it is then either in-situ stress state, the formation strength, or both of these quantities that should be amended. If the formation strength can be inferred from real-time measurements, such as compressional slowness data from the appropriate LWD tool or indentation tests on cuttings, then it may be assumed to be the most reliable parameter. The minimum change to the in-situ stress state (actually the maximum principal in-situ stress, as the minimum principal in-situ stress is constrained through fluid loss observations) is then made which allows prediction to match reality. If the formation strength cannot be inferred from real-time measurements, it should be assumed to be the most unreliable parameter and then amended until there is an adequate match between prediction and reality. The

method of updating the in-situ stress or formation strength is identical in both cases: it requires that these parameters are amended until the output of the models that has used to estimate the bounds to the drilling fluid density agrees with the real-time measurement. This is an iterative process.

Breakouts occurring at values of ECD that are lower then the predicted minimum values are expected. No change is therefore made to the mechanical earth model.

Suppose the nature, severity or extent of the drilling hazards, or geological characteristics, differ from their prognoses, or fluid or gas unexpectedly enters the wellbore. The diagnostic techniques outlined in above could be used to detect these events and the earth model could then be directly updated without further computation, although the ECD should be used to assess the severity of the drilling hazard and the expectation of fluid or gas entry into the wellbore. Other real-time information, such as palaeontological analysis of cavings or LWD resistivity data, should be used to assess the extent of any instability associated with the wellbore or adjacent geology.

The following example further illustrates how an earth model may be updated. After a well had been drilled to a depth of 2000m TVD (true vertical depth), it was decided to pull the drilling equipment out of the well. However, during this process 12 barrels of drilling fluid were lost to the formation. The real-time ECD measurement showed that this occurred at a pressure equivalent to 15.35 lb/gal. Figure 6

illustrates an example of the minimum principal in-situ stress in an earth model, according to a preferred embodiment of the invention. As shown in Figure 6, the minimum principal in-situ stress was therefore revised to be the equivalent of 15.35 lb/gal for the entire region above 2000m TVD.

As discussed, estimates along the trajectory of the upper and lower bounds of the drilling fluid density, together with the nature, severity and extent of the drilling hazards, allow the states of the wellbore, and geological features adjacent to it, to be predicted while the well is constructed. Examples of these are shown in Figures 7 and 8 for a well drilled in the North Sea. Figure 7 illustrates an example of the mud window (i.e. allowable drilling fluid densities) estimated prior to drilling the well. Drilling with a mud (i.e. fluid) whose density falls to the left of the solid line leads to breakouts. Conversely, drilling with a mud whose density falls to the right of the thick broken line will cause fluid loss into the formation. The vertical axis denotes the length of wellbore below the drilling rig floor. Figure 8 illustrates an example of drilling hazards, derived from an analysis of experience drilling offset wells, and the well trajectory shown in Figure 9. In figure 8, the severity of the hazard is shown as a "traffic light" classification. The vertical cross hatch indicates that the symptoms of the instability are present but insignificant: no remedial action is necessary. The horizontal cross hatch indicates that remedial action should be taken because the instability

is significant and could become serious. The diagonal cross hatch indicates that the instability is likely to result in loss of the well. The problem should be avoided, otherwise immediate remedial action should be taken. Figure 9 illustrates the trajectory of the well used in the examples of Figures 6-11. The Northerly and westerly directions are annotated (N and W, respectively). The vertical scale is true vertical depth below the drilling rig floor. Figure 10 illustrates the in-situ stress state prior to drilling the well used in Figures 6-11. In Figure 10, the symbols σ_V , σ_h and σ_H denote the vertical, minimum horizontal, maximum horizontal stresses, respectively and P_P is the pore pressure. TVD denotes true vertical depth with respect to the drilling rig floor. Figure 11 illustrates an example of the formation strength in the example of figure 6-11. The formation strength shown in Figure 11 is defined by the two parameters required to define the Mohr-Coulomb failure criterion. UCS and φ denote the uniaxial compressive strength and friction angle respectively.

The upper and lower bounds to the drilling fluid density may be derived by combining a prediction of the stress state around the wellbore embedded in an isotropic, homogeneous medium using an undrained linear elastic model with a Mohr-Coulomb failure criterion (Fjaer *et al.*, 1992), or through use of other techniques. The lower bound represents the minimum ECD that is required in order to prevent breakouts. The upper limit represents the maximum ECD that is

allowable before rock at the wellbore wall fractures or fluid is lost to the formation. These bounds may, however, have different physical interpretations if more sophisticated models (for example, the deformation of a salt formation) are used to derive them.

While preferred embodiments of the invention have been described, the descriptions and examples are merely illustrative and are not intended to limit the present invention.

CLAIMS

What is claimed is:

1. A method for updating an earth model comprising the steps of:

obtaining an earth model used for predicting potential problems in drilling of a borehole having a predetermined trajectory, the earth model comprising a plurality of components;

obtaining evaluations of the state of the borehole and local geological features, the evaluations being based on the earth model;

receiving data gathered during the construction of the borehole;

comparing the evaluations with a diagnosis of the state of the borehole and local geological features to identify at least one inconsistency, the diagnosis being based on the received data;

selecting a component of the earth model that is related to the identified inconsistency and has a high degree of uncertainty; and

updating the selected component of the earth model prior to completing construction of the borehole using the received data.

2. The method of claim 1 wherein the evaluations of the state of the borehole and local geological features include predictions of one or more conditions under which the borehole will fail.

3. The method of claim 2 wherein the predictions are obtained by combining the earth model with the predetermined trajectory of the borehole.

4. The method of claim 3 further comprising repeating the steps of combining, comparing, selecting and updating until a sufficient match exists between the predicted failure conditions and the diagnoses of the borehole.

5. The method of claim 4 wherein the step of combining when repeated uses the updated component of the earth model, and the step of selecting when being repeated, considers components that have been recently updated as having a lower degree of uncertainty.

6. The method of claim 1 wherein the step of selecting a component comprises:

identifying components of the earth model that are relevant to the identified inconsistency; and

ranking the identified components according to the degree of uncertainty.

7. The method of claim 1 wherein the selected component is the component having the highest degree of uncertainty of the components that are related to the identified inconsistency.

8. The method of claim 1 wherein the step of updating comprises effecting the minimum practical changes to the selected component that eliminates an identified inconsistency.

9. The method of claim 1 wherein the received data includes the effective density of the drilling fluid used in the construction of the borehole and one at least other parameter, and the step of updating comprises updating the selected component using the effective density and the at least one other parameter.

10. The method of claim 1 wherein the diagnosis of the borehole is generated by extensive use of real-time MWD and LWD measurements.

11. The method of claim 1 wherein the step of obtaining an earth model includes generating the earth model.

12. A method for drilling a borehole using an earth model comprising the steps of:

obtaining an earth model used for predicting potential problems in drilling of a borehole having a predetermined trajectory comprising a plurality of components;

predicting one or more conditions under which the borehole will fail based on the earth model and the predetermined trajectory;

drilling part of the borehole substantially according to the predetermined trajectory;

receiving data gathered during the construction of the borehole;

comparing the predicted failure conditions with a diagnoses of the borehole based on the received data to identify at least one inconsistency;

selecting a component of the earth model that is related to the identified inconsistency and has a high degree of uncertainty;

updating the selected component of the earth model prior to completion of the borehole using the received data; and

thereafter drilling a further portion of the borehole using the earth model including the updated component.

13. The method of claim 12 further comprising repeating the steps of predicting, comparing, selecting and updating until a sufficient match exists between the predicted failure conditions and the diagnoses of the borehole.

14. The method of claim 13 wherein the step of combining when repeated uses the updated component of the earth model, and the step of selecting when being repeated, considers components that have been recently updated as having a lower degree of uncertainty.

15. The method of claim 12 wherein the step of selecting a component comprises:

identifying components of the earth model that are relevant to the identified inconsistency; and

ranking the identified components according to the degree of uncertainty.

16. The method of claim 12 wherein the step of updating comprises effecting the minimum practical changes to the selected component that eliminates an identified inconsistency.

17. The method of claim 12 wherein the received data includes the effective density of the drilling fluid used in the construction of the borehole and one at least other parameter, and the step of updating comprises updating the selected component using the effective density and the at least one other parameter.

18. A computer readable medium that is capable of causing a computer to perform steps comprising:

obtaining an earth model used for predicting potential problems in drilling of a borehole having a predetermined trajectory, the earth model comprising a number of components;

obtaining evaluations of the state of the borehole and local geological features, the evaluations being based on the earth model;

receiving data gathered during the construction of the borehole;

comparing the evaluations with a diagnosis of the state of the borehole and local geological features to identify at least one inconsistency, the diagnosis being based on the received data;

selecting a component of the earth model that is related to the identified inconsistency and has a high degree of uncertainty; and

updating the selected component of the earth model prior to completing construction of the borehole using the received data.

19. The computer readable medium of claim 18 capable of causing a computer to perform steps further comprising:

identifying components of the earth model that are relevant to the identified inconsistency; and

ranking the identified components according to the degree of uncertainty.

20. The computer readable medium of claim 19 wherein the step of updating comprises effecting the minimum practical changes to the selected component that eliminates an identified inconsistency.

21. The computer readable medium of claim 20 wherein the received data includes the effective density of the drilling fluid used in the construction of the borehole and one at least other parameter, and

the step of updating comprises updating the selected component using the effective density and the at least one other parameter.

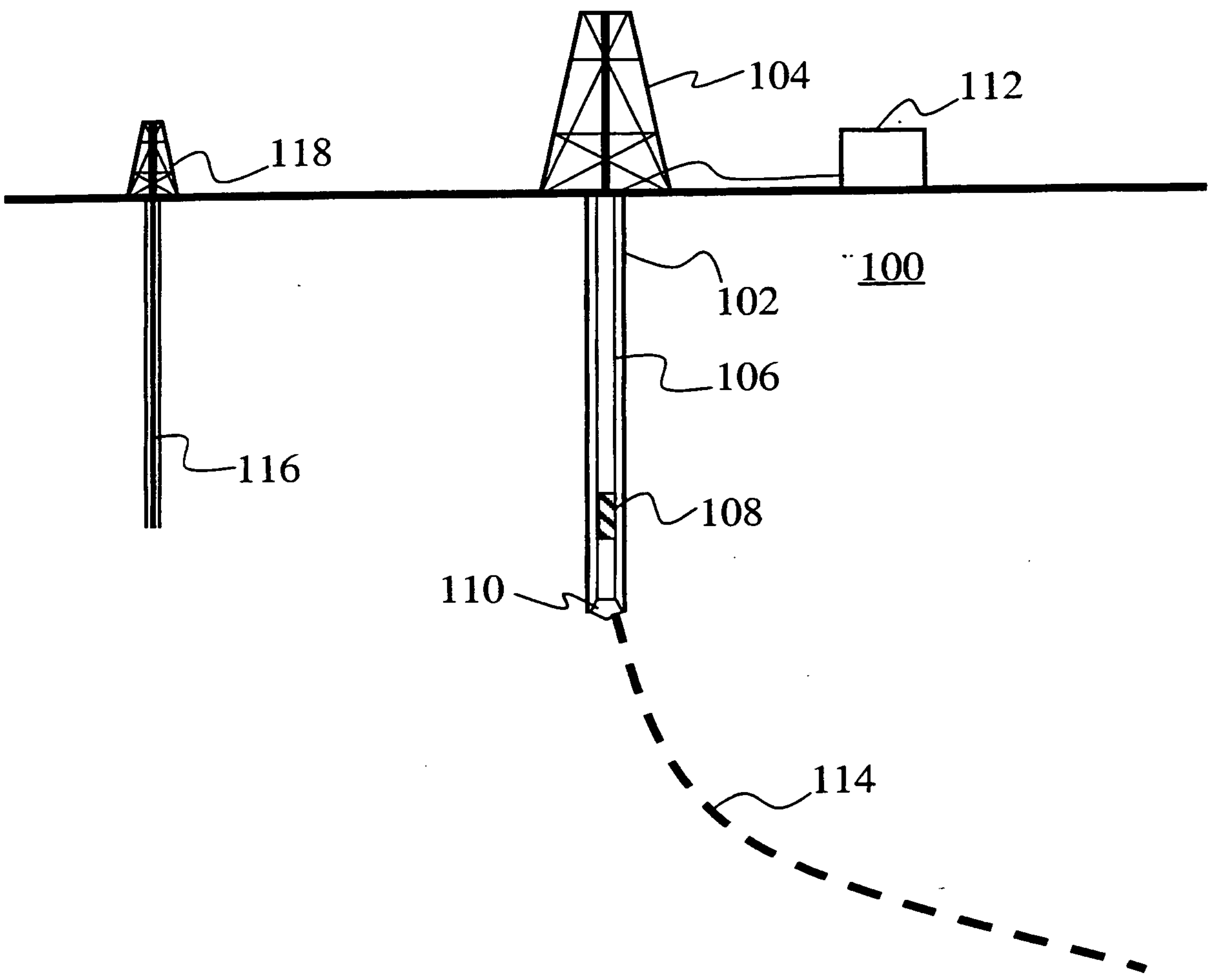


FIG. 1

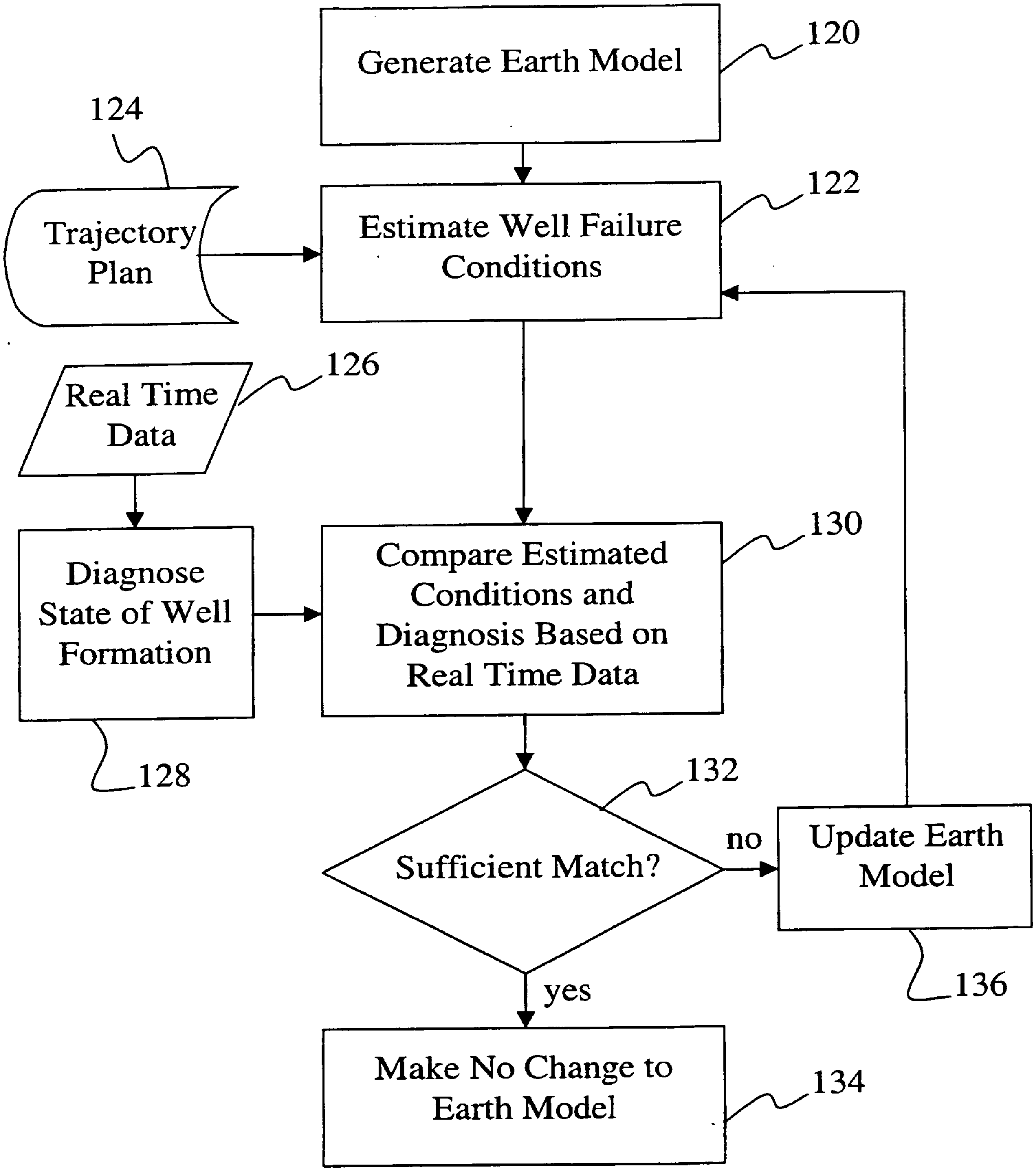

Generate Earth Model
120
124
Trajectory Plan
Estimate Well Failure Conditions
122
Real Time Data
126
Diagnose State of Well Formation
128
Compare Estimated Conditions and Diagnosis Based on Real Time Data
130
Sufficient Match?
132
no
Update Earth Model
136
yes
Make No Change to Earth Model
134

FIG. 2

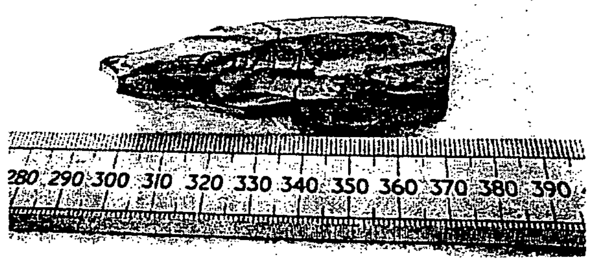


FIG. 3a

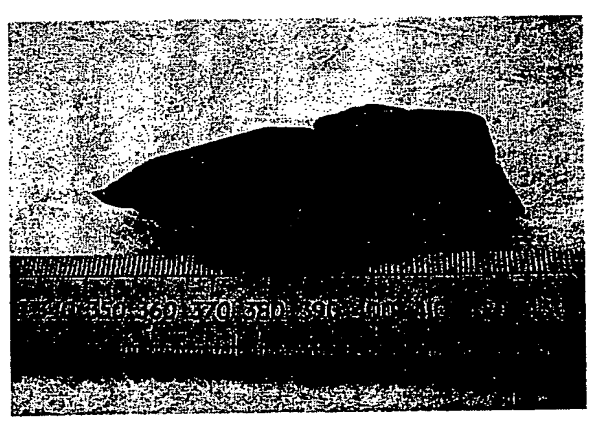


FIG. 3b

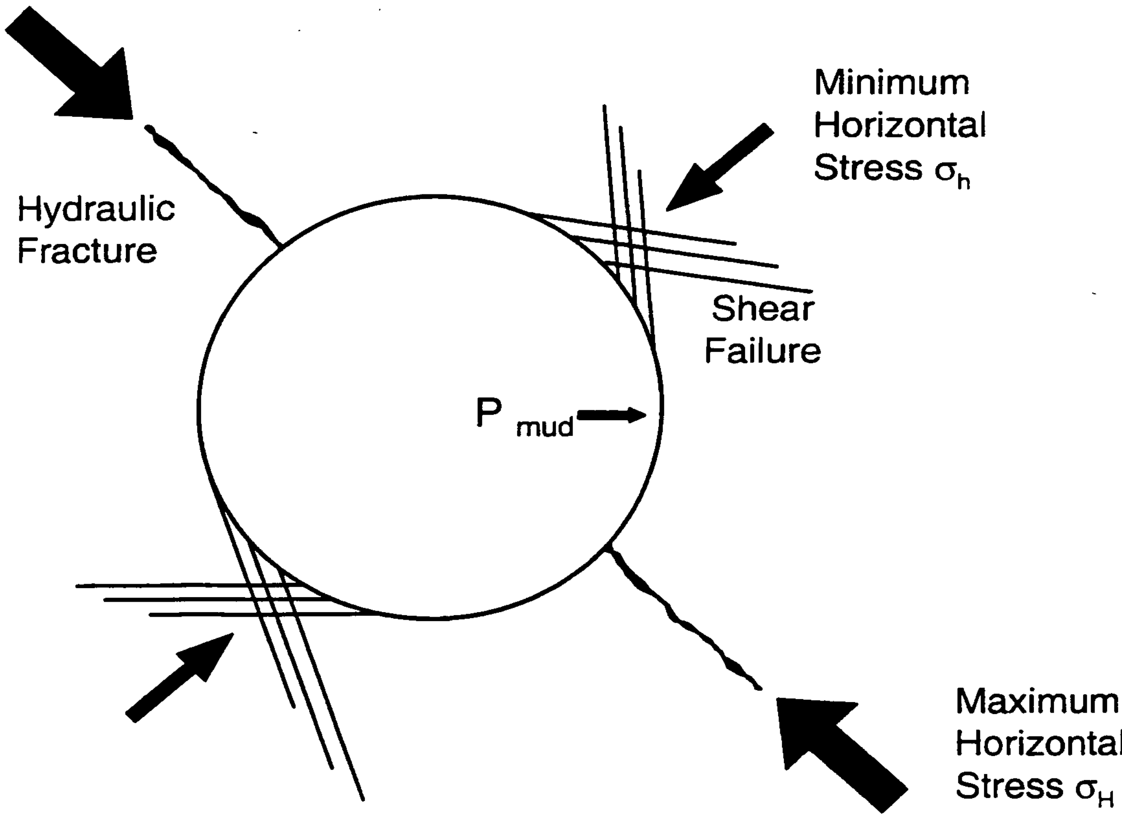

Minimum
Horizontal
Stress σ_h
Hydraulic
Fracture
Shear
Failure
P_{mud}
Maximum
Horizontal
Stress σ_H

FIG. 4

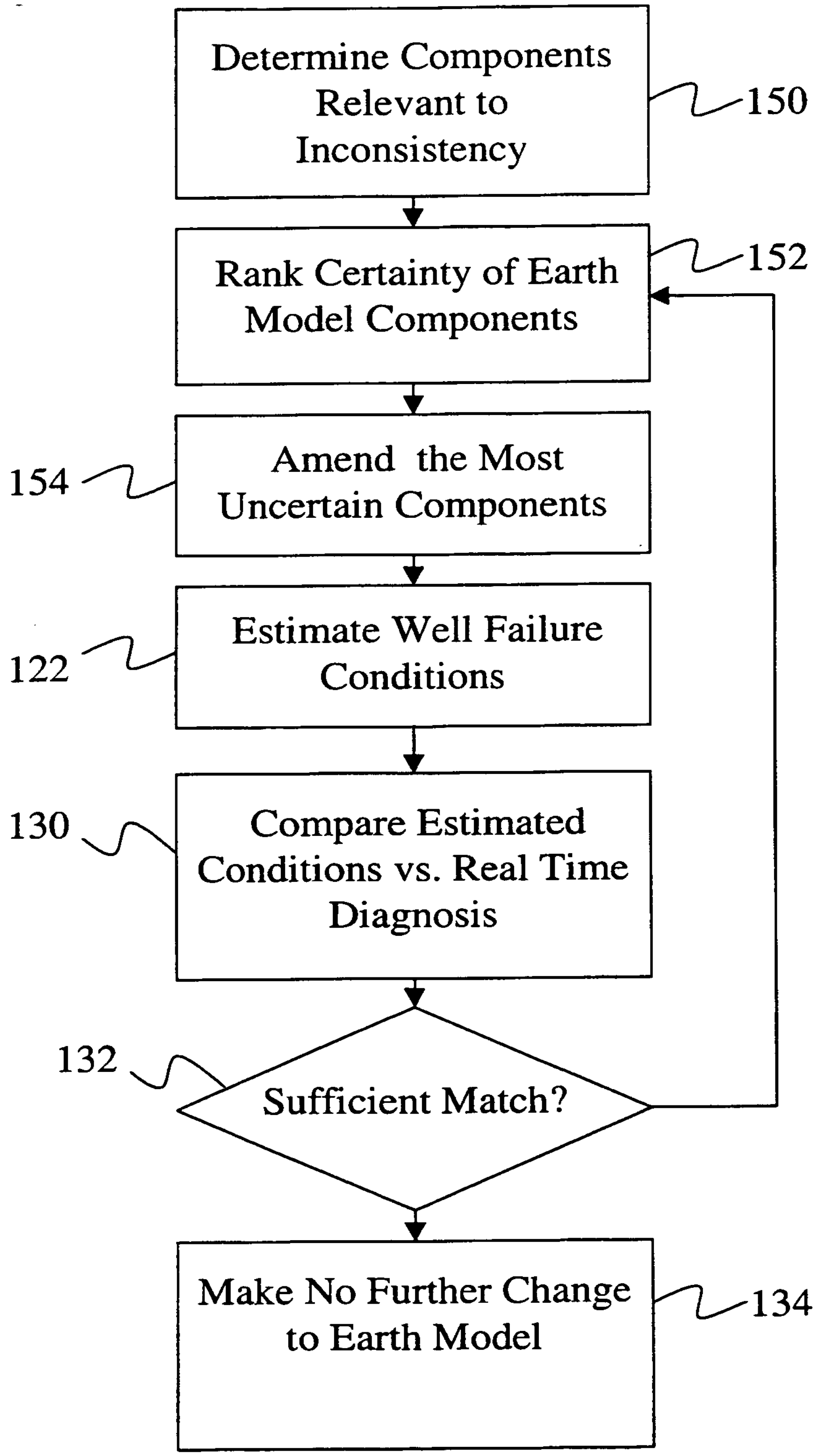
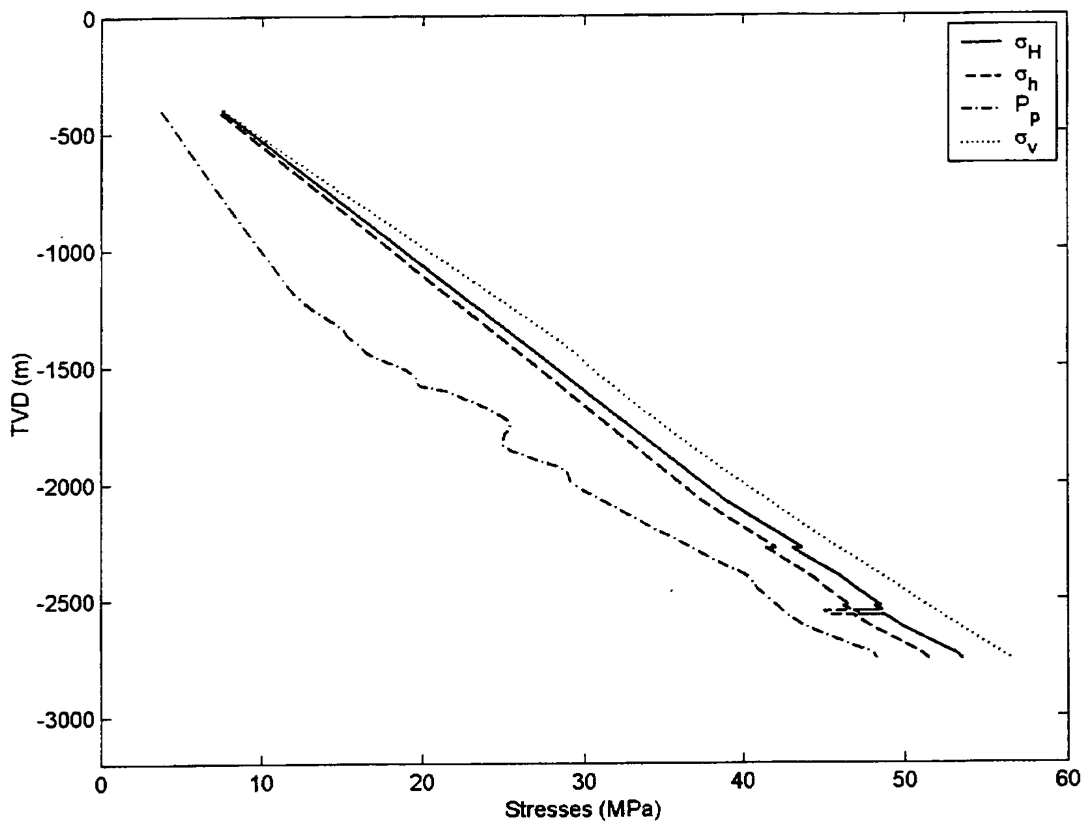

Determine Components Relevant to Inconsistency
150
Rank Certainty of Earth Model Components
152
154
Amend the Most Uncertain Components
122
Estimate Well Failure Conditions
130
Compare Estimated Conditions vs. Real Time Diagnosis
132
Sufficient Match?
Make No Further Change to Earth Model
134

FIG. 5



0
-500
-1000
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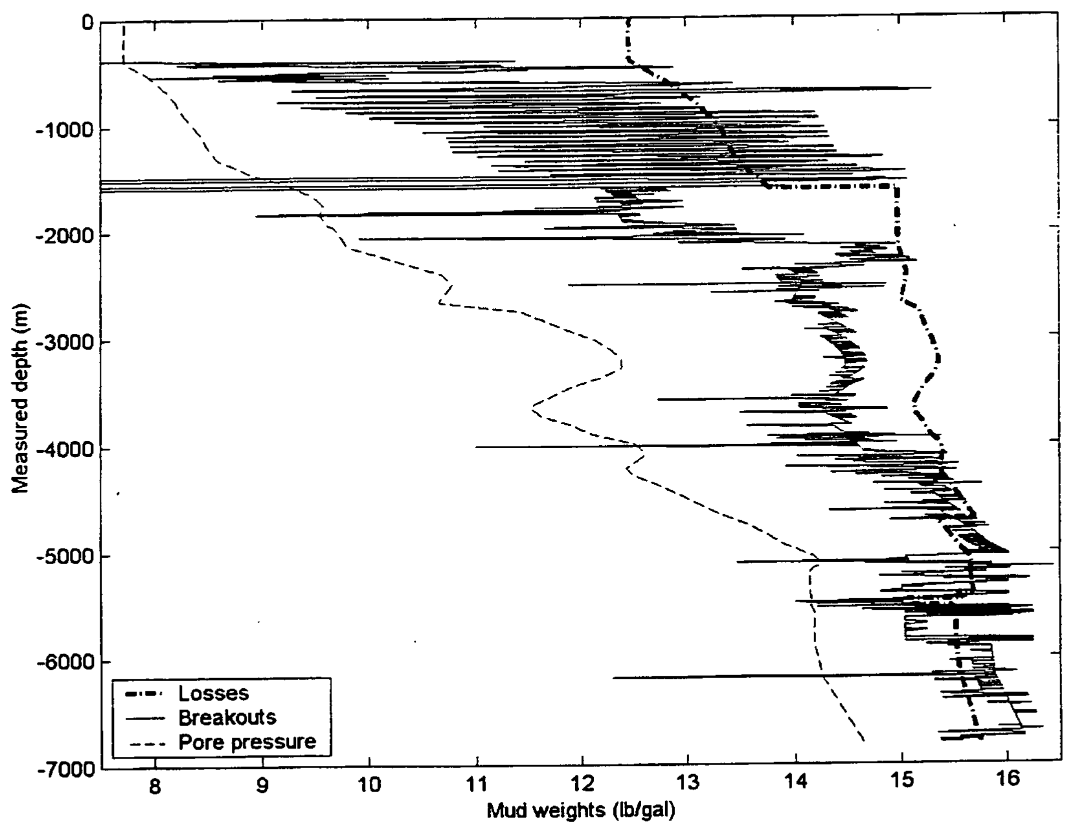
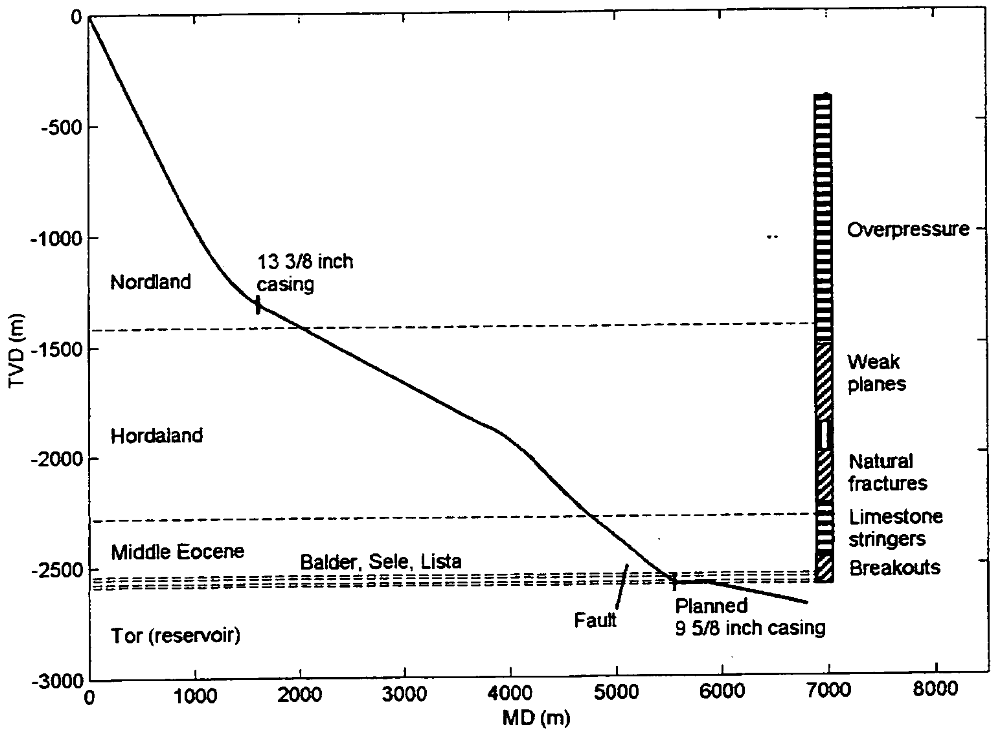
-3000
TVD (m)
0
10
20
30
40
50
60
Stresses (MPa)
σH
σh
Pp
σv

FIG. 6



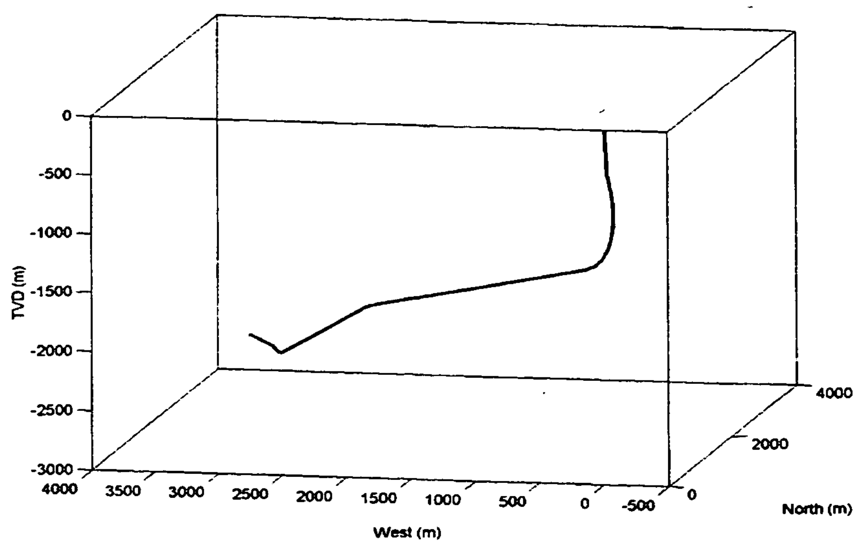
Losses
Breakouts
Pore pressure
Measured depth (m)
0
-1000
-2000
-3000
-4000
-5000
-6000
-7000
8
9
10
11
12
13
14
15
16
Mud weights (lb/gal)

FIG. 7



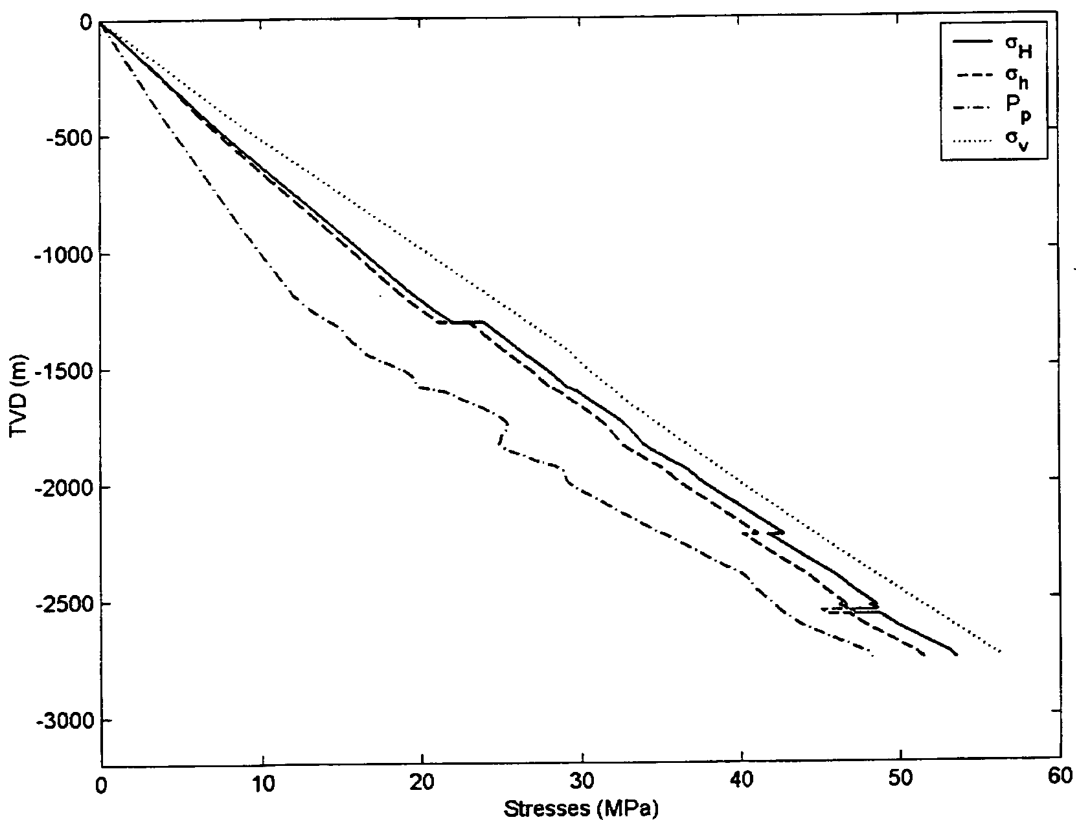
0
-500
-1000
-1500
-2000
-2500
-3000
TVD (m)
Nordland
13 3/8 inch casing
Hordaland
Middle Eocene
Balder, Sele, Lista
Tor (reservoir)
Fault
Planned 9 5/8 inch casing
Overpressure
Weak planes
Natural fractures
Limestone stringers
Breakouts
0
1000
2000
3000
4000
5000
6000
7000
8000
MD (m)

FIG. 8



0
-500
-1000
-1500
-2000
-2500
-3000
TVD (m)
4000
3500
3000
2500
2000
1500
1000
500
0
-500
West (m)
0
2000
4000
North (m)

FIG. 9



0
-500
-1000
-1500
-2000
-2500
-3000
TVD (m)
0
10
20
30
40
50
60
Stresses (MPa)
σ_H
σ_h
P_p
σ_v

FIG. 10

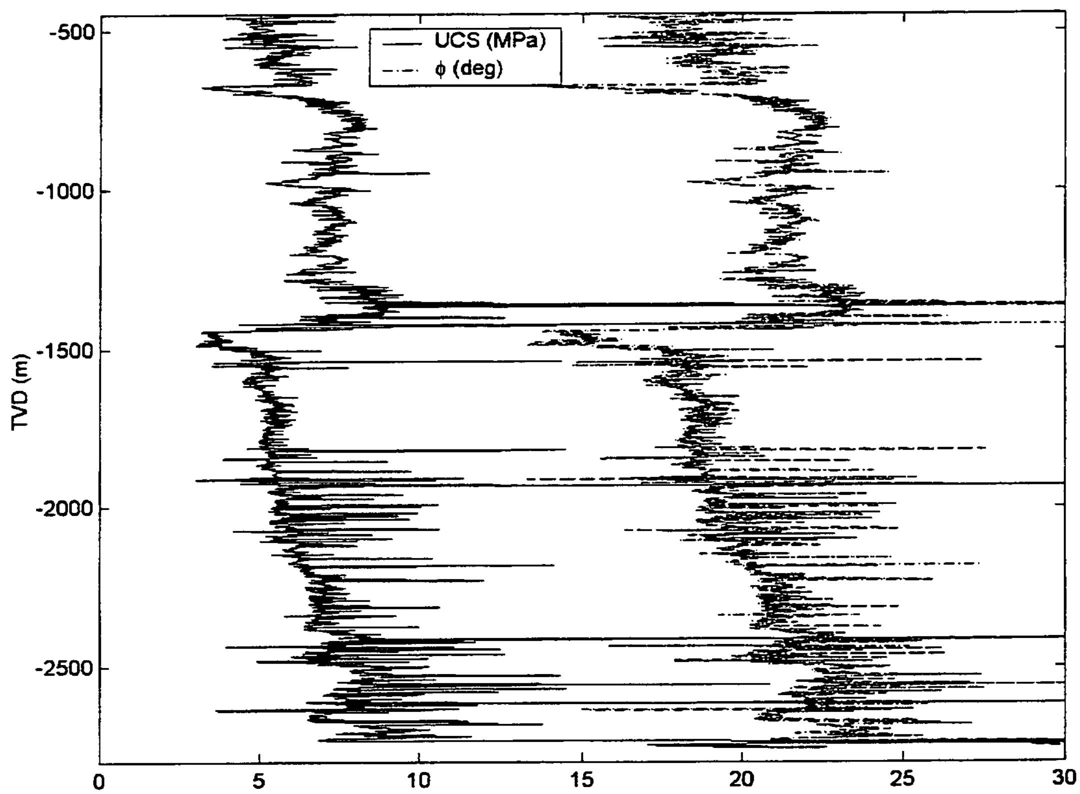


FIG. 11

INTERNATIONAL SEARCH REPORT

Intern. nal Application No
PCT/GB 00/03704

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G01V11/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G01V

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, COMPENDEX, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
P,X	US 5 995 446 A (MEYER JOERG H ET AL) 30 November 1999 (1999-11-30) column 3, line 23 - line 45 column 4, line 12 - line 50 column 4, line 62 -column 5, line 6; claim 1	1,12,18
A	WO 97 27502 A (BAKER HUGHES INC) 31 July 1997 (1997-07-31) page 1, line 9 - line 16 page 8, line 13 - line 16 page 13, line 10 - line 14 page 38, line 21 -page 39, line 9	1,12,18
A	US 5 838 634 A (HELWICK JR STERLING J ET AL) 17 November 1998 (1998-11-17) column 6, line 48 -column 7, line 67	1,12,18

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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"A" document defining the general state of the art which is not considered to be of particular relevance

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"P" document published prior to the international filing date but later than the priority date claimed

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
13 December 2000	20/12/2000

Name and mailing address of the ISA	Authorized officer
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International Application No
PCT/GB 00/03704

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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